Resources

Expert Advice: Tunable RF Filters: Pursuing the 'Holy Grail' of Acoustic Filter R&D

A bulk acoustic wave (BAW) filter with ground-breaking, standard-setting performance would offer a tuning range far beyond today's established outer limits. Can the center frequency tuning range of BAW filters be extended beyond 2% up to 5%, or perhaps even three to four times that amount?

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Mon. June 16, 2008

Introduction

Wireless broadband communications relies on a combination of SAW and BAW technologies for reliable and cost-effective signal filtering. Established performance and feasibility norms are constantly challenged. While many seemingly impossible tasks have been accomplished in recent years, filter researchers have nevertheless found certain desirable characteristics remain beyond their reach – the so-called 'Holy Grail' of acoustic research. By nature, their development would usher in a new era of product manufacturing by altering system design paradigms. A bulk acoustic wave (BAW) filter with ground-breaking, standard-setting performance would offer a tuning range far beyond today's established outer limits. Can the center frequency tuning range of BAW filters be extended beyond 2% up to 5%, or perhaps even three to four times that amount?

Today's mobile phone filter technology

RF filters traditionally used for cell phone applications are based on surface acoustic wave (SAW) technology. The selectivity of SAW filters is good for a band at 1 GHz but degrades when the band is located closer to the upper limit of 2.5 GHz. Temperature drift is also a concern. For broadband communication systems above 2 GHz, the only solutions offering more than 5% bandwidth are dielectric filters, waveguide filters and LC filters, each of them having severe drawbacks in terms of size, selectivity or cost. Many of the emerging broadband systems require a relative a filter bandwidth of 15% in order to cover bands used in different regions/countries, while the "true" channel bandwidth is typically less than 2%.

SAW technology serves classic cell phone applications (all four GSM bands and all CDMA bands except the US-PCS band) very well. SAW technology is very mature and every aspect of the manufacturing process is optimized to achieve aggressive cost targets. The US-PCS band, with its narrow transition range of 20 MHz between transmit (Tx) and receive (Rx) bands, provides challenges which are difficult to overcome with conventional SAW technology. Two flavors of bulk acoustic wave devices (BAW-SMR and FBAR) have successfully filled this void in recent years, granting BAW a solid position in the wireless phone market.

In comparing SAW and BAW technologies, it should be noted that BAW-based products have inherent advantages with regard to losses. Acoustic energy density is very high in BAW designs and the waves are very well trapped. The Quality Factors (Q-value) that can be achieved with BAW resonators are superior to any other technology suitable for the GHz range. Q-values above 2000 at 2GHz represent the state of the art for FBARs and SMR-BAWs. As a result of the high Q-values, the filter skirts will be very steep while the insertion loss remains low even at the edges of the passband. This is a key advantage for duplexers in the US-PCS band and the main reason FBAR and BAW were able to conquer a large market share in this particular application. BAW-SMRs also have significantly less temperature dependency and exhibit particularly favorable TCF compared to SAW, typically -17 ppm/C. All this having been established and proven in the marketplace, the most important advantage of BAW-SMR is the fact that frequencies up to 6 GHz can be addressed without running into practical manufacturing limits. The thickness of the layers to be deposited scale with 1/f, while the size of a BAW resonator scales with 1/f2 . Both parameters make it favorable to use BAW at high frequencies, but conversely, make it hard for BAW products to compete at low frequencies, say 1 GHz.

The 'Holy Grail' of Filter Design...

While today's BAW filter products manufactured in state-of-the-art facilities can be produced with relative economy, the overall cost differential between SAW and BAW remains a factor in determining its suitability for a given application. But because of BAW's higher frequency performance, ESD robustness, resistance to loss and temperature reliability, it's appropriate to speculate about the future of BAW developments as 3G / 4G mobile communications look to higher frequencies for next-generation applications.

Forecasting the future of device development takes one beyond the practical limits of today's technology. Some products can exist today only in a designer's fantasy due to such limits. But based on a belief that certain performance is achievable, or so desirable that the complexities of designing such a product will one day be overcome, a product road map extending beyond the edges of 'possible' becomes conceivable.

One such product, a "Holy Grail" of RF filters, is a low-loss and highly selective filter with a small size that has an electrically tunable center frequency. Tunable electromagnetic-cavity filters for bench top experiments exist, but they are the size of a shoebox. Filters based on tunable capacitors of various kinds suffer from excessive losses, if not in the capacitors then definitely in the inductors needed in the resonance elements.

Unfortunately, there is no simple way to change the frequency of acoustic filters on the fly. The tuning range achievable with existing methods and materials is ridiculously small. The piezoelectric effect is not strong enough relative to the stiffness of the bulk material to create static deformation or stresses great enough to substantially change the frequency of a SAW or BAW. Even if a DC bias voltage of 50V is applied across a resonator, the frequency change is typically less than 0.5%. However, new compounds belonging to the class of electro-active, electrostrictive and ferroelectric materials show a much more pronounced effect and may in the future provide a solution to build electrically tunable acoustic filters. A tuning range of 5% would draw attention, but 20% would be truly disruptive; this would have a major impact on the architecture of future RF systems.

Academic research in the area of electrostrictive materials such as Strontium-Titanate has picked up significantly over the last three years and several startup companies are selling the idea of tunable filters to potential investors. Another physical effect of interest for tunable acoustic devices is found in phase-change-materials often referred to as "Shape-Memory alloys"; those alloys exhibit a significant change in all material parameters triggered by tiny changes in thermodynamic conditions.

Are we there yet?

As any engineer recognizes, products that can only be theorized at one point in time often become the fodder of actual device development. Why? Materials or processes that did not exist previously now become obtainable, or, advances in the underlying physics allow researchers to overcome long-established 'absolutes.' Any number of breakthroughs along product development cycles can result in a redefinition of what is, or isn't, possible.

We are at a point where material research in combination with acoustic device expertise could yield advances beyond what is accepted today as the outer limit of BAW device performance. What do you think?

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